Derivation and measurement of the M/# in spectral hole burning media

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Derivation and measurement of the M/# in spectral hole burning media

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Abstract

We demonstrate 10 plane wave holograms angularly multiplexed at one frequency channel in spectral hole burning medium. We show that the M/# is still a valid system metric and the measured M/# in one frequency channel is about 0.01.

Keywords: Spectral hole burning holography, M/#, angular multiplexing

1. Introduction

Spectral hole burning holography can store both the temporal and spatial information. In cryogenic temperature, only a certain group of atoms in the spectral hole burning material can interact with the incident photons of specific frequency. It allows for an extra degree of freedom to store and access information, i.e. the frequency domain. 12,000 holograms at a single location by frequency multiplexing has been demonstrated[1,4]. The storage capacity can be further increased by combining angle and frequency multiplexing. In this paper, we propose to investigate the recording of multiple holograms at a single location and frequency using either angular or peristrophic multiplexing. A system measure of the diffraction efficiency of multiple holograms superimposed in the same volume is called the M/#[2]and is used extensively with photorefractive crystals and photopolymers. It is defined by $M/\#=M\eta^{1/2}$, where M is the number of superimposed holograms and η is the equalized diffraction efficiency of each individual holograms. In this paper, we report on the measurement of the M/# in spectrally selective media.

2. Experiment

The spectral hole burning material used in our experiments is H_2TBNP in polyvinyl butyral (PVB)[3] with a concentration of 3×10^{-5} mol/l. The thickness of the sample is 400 μm. We used a cw laser diode (790nm) to measure the M/# in one frequency channel. The results can be extended to other frequency channels as well. Our experimental setup is shown in Fig.1.

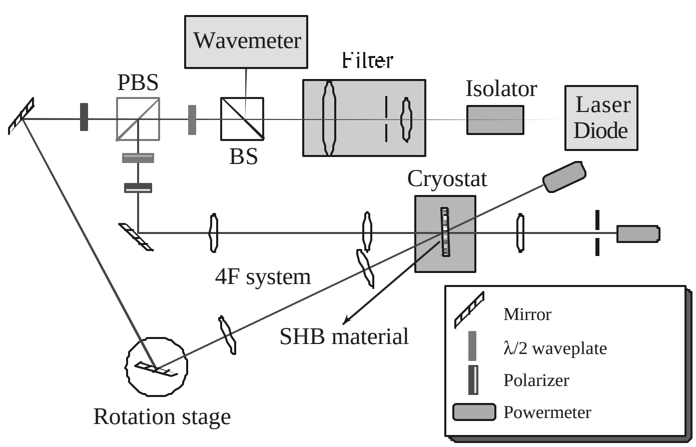

Fig.1 Spectral hole burning experimental setup

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The sample is put in a cryostat immersed with liquid Helium. The reference beam angle can be changed by rotating the mirror which is mounted in a rotation stage. Figure 2 shows the absorption kinetics measured at 2 Kelvin.

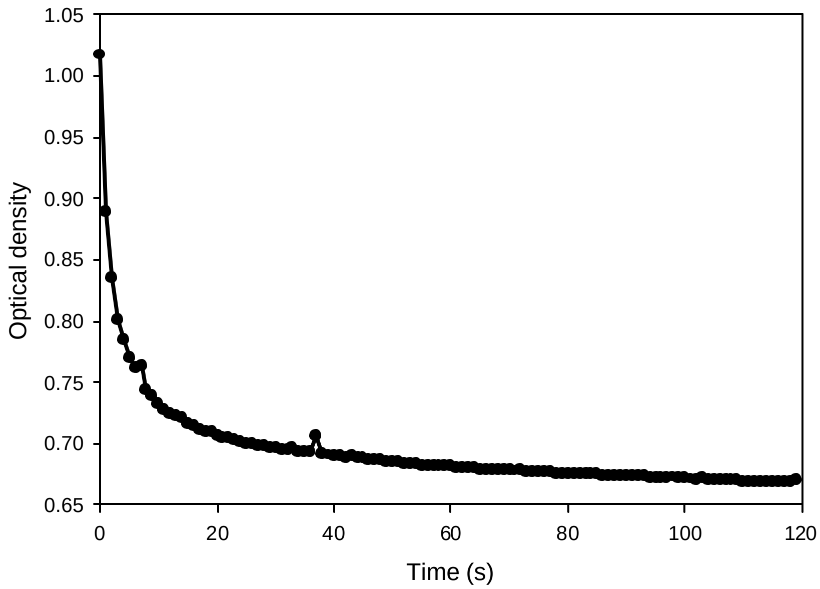

Fig.2 Bleaching kinetics of H_2TBNP:PVB at 2K

The bleaching beam intensity is about 10 μW/cm^2. The intensity transmission coefficient T satisfies T=exp(-2ad), where a is the absorption coefficient and d is the thickness of the material. We define the optical density as OD=ad=-0.5lnT. Single plane wave hologram is recorded at different wavelengths with both the reference and the signal intensity of 10 μ W/cm^2. Figure 3 shows the reading curves of the single plane wave hologram with the unattenuated original reference beam.

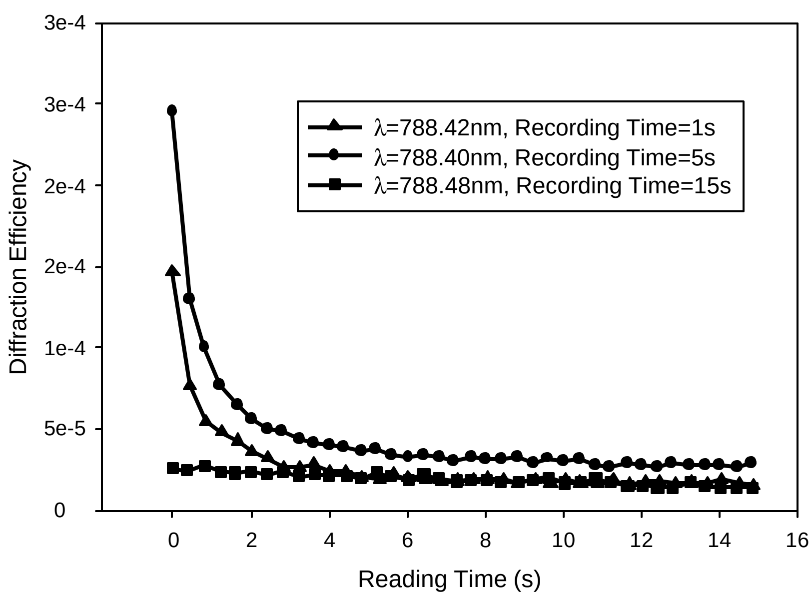

Fig. 3 Destructive reading of the spectral hole burning holograms

A diffraction efficiency of 10^{-4} can be consistently obtained. The optimal recording time lies between 5-8 seconds. Due to the mechanical oscillation of the cryostat we have difficulty to get consistent grating growth curves.

Figure 4 shows the measured angular selectivity curve without using the iris filter in front of the power meter(see Figure 1).

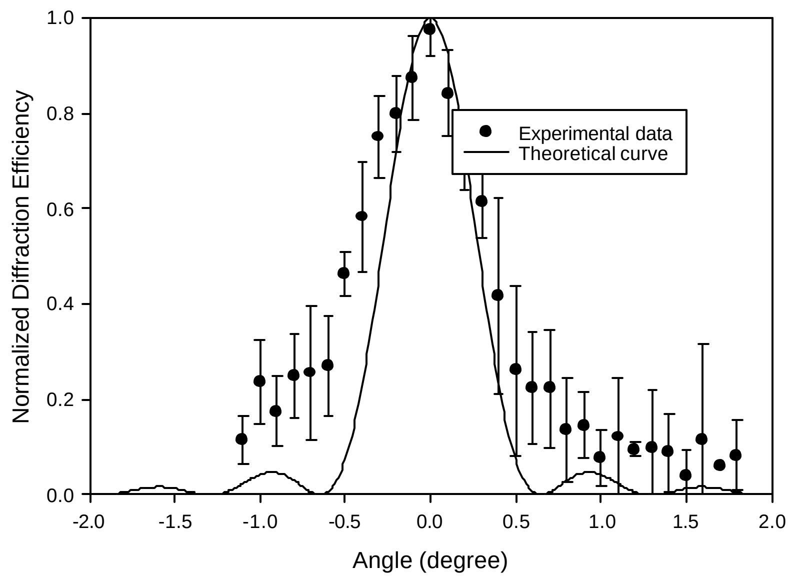

Fig.4 Angular selectivity

The selectivity is about 0.6 degree and agrees with the theoretical result well. However the data is very noisy due to the scattering from the sample. An iris filter is then used at the back focal plane of the Fourier lens after the sample. This serves for two purposes. One is to reduce the scattering and background noise, and the other is to further reduce the selectivity. For thin material, if the reference beam angle is changed slightly the reconstructed signal beam angle is changed accordingly and can get partially blocked by the iris filter. The filter gives us a combined effect of both angular and peristrophic selectivity. The selectivity curve with the iris filter is shown in Figure 5. A selectivity of about 0.2 degree is obtained, which is consistent with the iris diameter of about 1mm and the Fourier lens focal length of about 24cm.

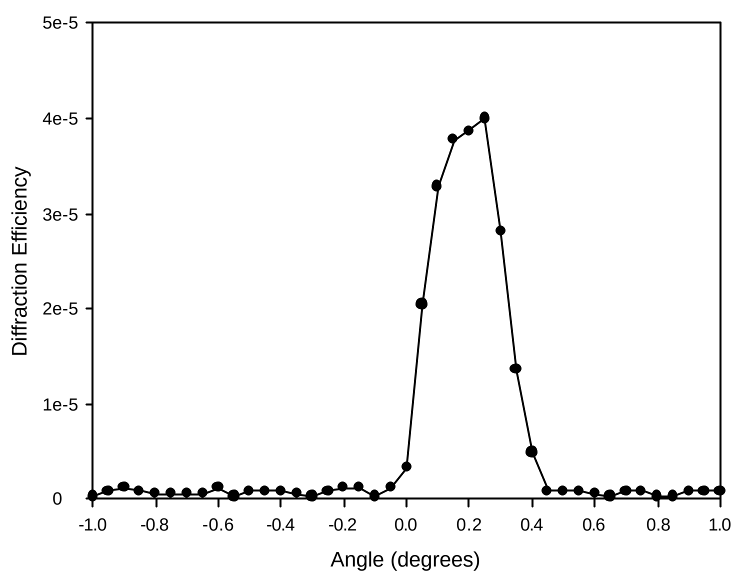

Fig.5 Angular selectivity with an iris filter

Three, five, seven and ten plane wave holograms are then angularly multiplexed and the comb functions are shown in Fig. 6. Equal time (1s-2s) exposure schedule is used.

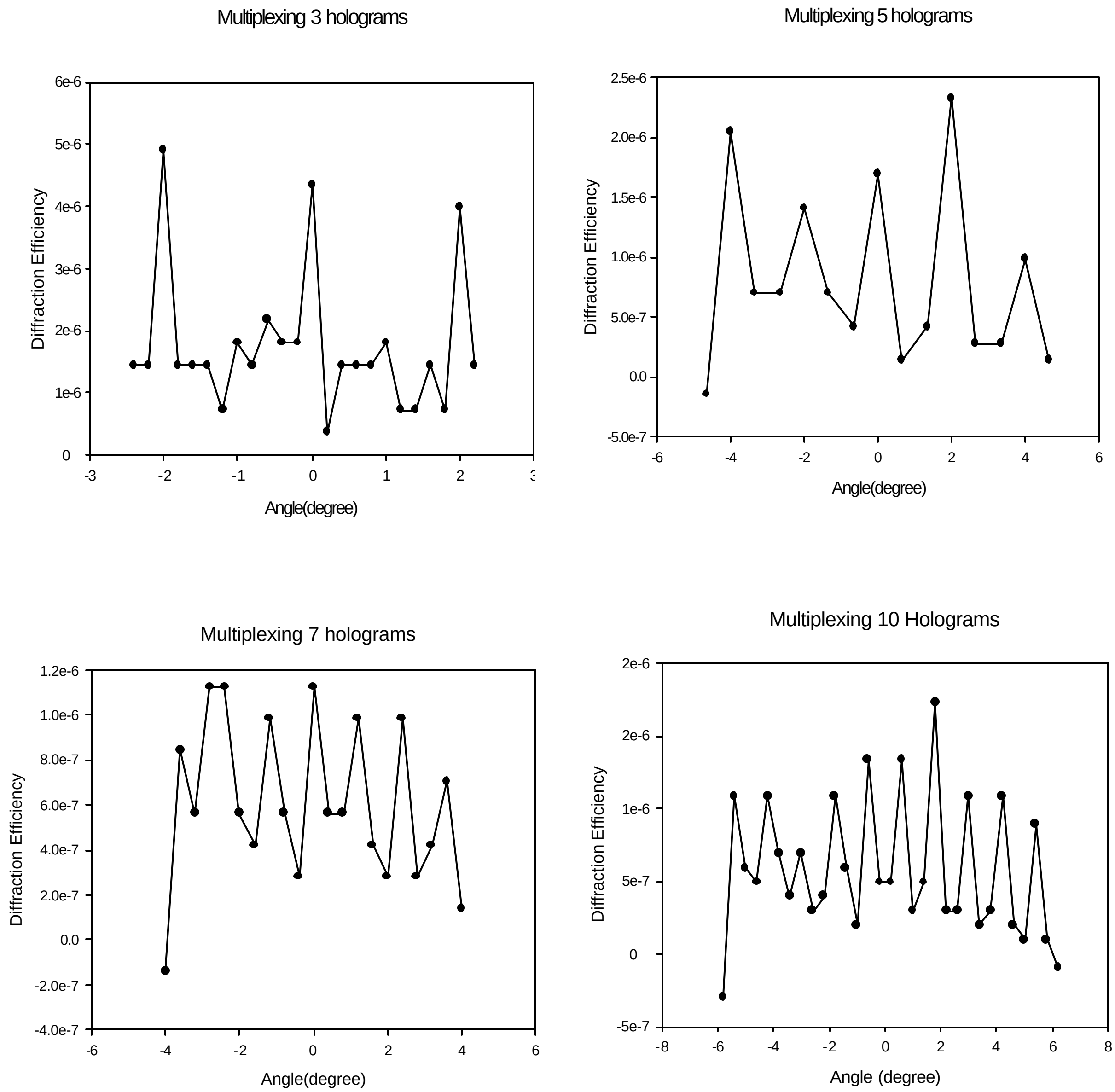

Fig. 6 Angularly multiplex plane wave holograms in spectral hole burning medium

Figure 7 shows the measured M/# of each case. As we multiplex 3,5,7 and 10 holograms, the M/# has a trend to increase. This is because the total exposure energy increases and we better use the dynamic range of the material. The measured M/# is about 0.01.

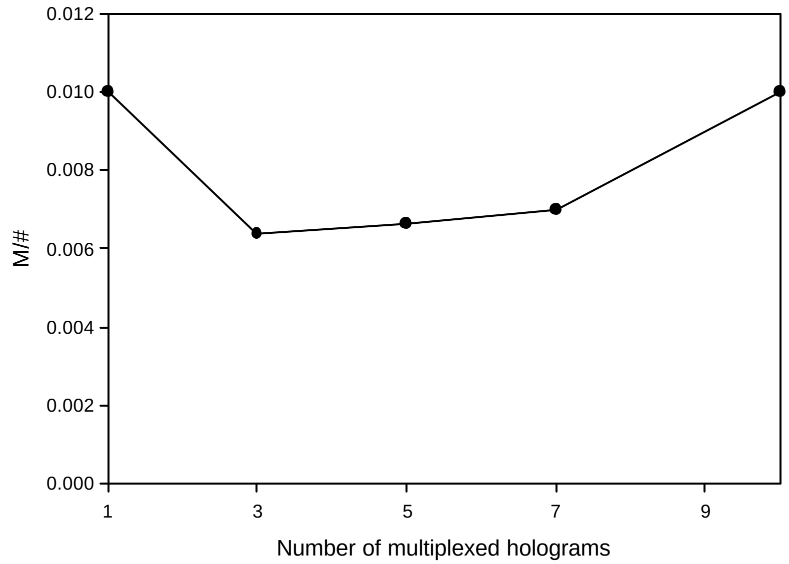

Fig. 7 Measured M/# in one frequency channel

3. Theory

We also studied the recording dynamics when 10 holograms are recorded using numerical simulation. The non-uniform grating recording due to light absorption inside the material is taken into account. The diffraction efficiency of each hologram is equal and maximized by numerically searching for the optimal exposure schedule. Fig. 8 shows the dependence of the calculated M/# on material thickness.

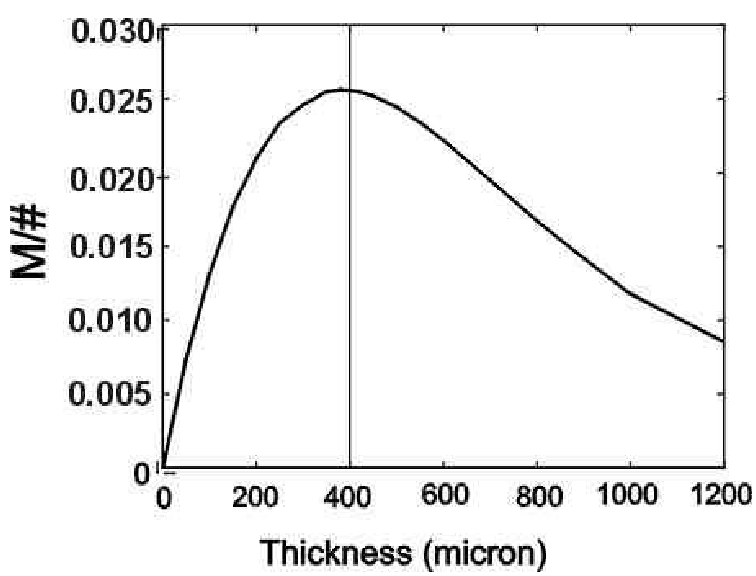

Fig. 8 Calculated M/#

The M/# first increases linearly with the thickness of the material as in the photorefractive crystal. However, it has an optimal thickness and if the material is too thick the M/# decreases due to strong absorption of the diffracted light. The material used in our experiments has optimal thickness and the calculated M/# is about 0.025 which is consistent with what we measured.

4. Conclusion

We recorded 10 angularly multiplexed plane wave holograms and we show that M/# is still a valid system metric for SHB holography. The measured M/# is 0.01 which is consistent with the calculated M/# of 0.025 obtained from dynamic simulation. The discrepancy is mainly due to non-optimal usage of the dynamic range and not optimized exposure schedule.

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